APPLICATION OF THE IRIDIUM SATELLITE SYSTEM TO AERONAUTICAL COMMUNICATIONS

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Abstract

The next generation air transportation system will require greater air-ground communications capacity to accommodate more air traffic with increased safety and efficiency. Communications will remain primarily terrestrially based, but satellite communications will have an increased role. Inmarsat's aeronautical services have been approved and are in use for aeronautical safety communications provided by geostationary satellites. More recently the approval process for the Iridium low earth orbit constellation is nearing completion. The current Iridium system will be able to provide basic air traffic services communications suitable for oceanic, remote and polar regions. The planned second generation of the Iridium system, called Iridium NEXT, will provide enhanced capabilities and enable a greater role in the future of aeronautical communications. This paper will review the potential role of satellite communications in the future of air transportation, the Iridium approval process and relevant system testing, and the potential role of Iridium NEXT.

1. Introduction

Expansion of the performance and capacity of communications to and from aircraft underlies plans for the next generation global air traffic system. Europe's SESAR Program and the NextGen Program in the US are proceeding on the definition of an air transportation system that envisions major transformation of the world's most densely crowded airspace to enable continued growth in capacity while addressing safety and environmental concerns.

The Future Communications Study (FCS), a joint product of Eurocontrol and the U. S. Federal Aviation Administration (FAA), initiated the process of planning for next generation aviation communications to meet future air traffic needs. Satellite communications were among several technologies studied. Based on the FCS assessment of future communications requirements, current satellite communications systems operating in aviation safety communications frequency bands, namely Inmarsat and Iridium, were deemed unable to meet all of the future requirements, but were capable of meeting the requirements in certain regions, particularly in oceanic, remote, and (in the case of Iridium) polar airspace.

Within the International Civil Aviation Organization (ICAO) Aeronautical Communications Panel, preparation of suitable global standards to enable application of the Iridium Satellite System to aviation safety communications has recently been completed. Preparation of technical standards within such standards bodies as RTCA and AEEC are nearing completion, after which approval for the use of Iridium for safety-related air traffic services (ATS) communications can commence.

The next generation of the Iridium Satellite System is now being planned. Iridium NEXT will be capable of providing increased capabilities that can be applied to aeronautical communications. As the system design for Iridium NEXT is fully developed, it can be assessed against expected future air transportation system communications requirements to determine its potential future role.

2. Future Communications Study

At the ICAO Air Navigation Commission Meeting #11 in 2003, a need for a future air-ground communications system for air traffic management (ATM) communications on which different regions of the world could eventually converge was identified. Diverging air-ground communications systems under development in different regions of the world had met with resistance from airspace system users who operated in multiple regions as being too difficult and expensive to implement.

The FAA and Eurocontrol initiated the FCS to develop solutions to the need identified by ICAO. The FCS delivered its final report to ICAO in October, 2007 [1]. The FCS included operational concepts, communications requirements, analysis of business and institutional elements, and identification and assessment of technology alternatives. The Communications Operating Concept and Requirements (COCR) was jointly developed by the US and European teams to reflect expected communications requirements in an interim implementation phase (Phase 1 beginning in 2015) and a final phase (Phase 2, from 2020 through full implementation by 2030). The COCR provided a primary requirement against which the various communications technologies were assessed.

The FCS technology identification and assessment consisted of three phases. The first phase identified existing communications technologies that could be applied to the COCR requirements and screened those technologies against evaluation criteria to determine the best candidates. The second phase performed detailed technical evaluations of the top candidates to determine their potential performance under expected conditions and operational scenarios. The third phase focused on in-depth studies of important technical details of the top-ranked technologies. The FCS then downselected a subset of technologies for final evaluation. This subset is shown in Table 1.

Table 1 – FCS Evaluated Technologies

United States	Common Technologies	Europe
Continental Airspace		
	P-34/TIA-902	B-AMC
	LDL	AMACS
	W-CDMA	Custom Satellite
Oceanic and Remote Airspace		
	Inmarsat SwiftBroadband	
	Custom Satellite	
Airport Surface		
	IEEE 802.16e	

For continental airspace, the P34/TIA 902 (Public Safety Communications Standard APCO Project 34/ Telecommunications Industry Association Standard 902), LDL (VHF Digital Link Mode 3 in L-band), and wideband CDMA were jointly selected by the US and Europe for thorough evaluation. Europe additionally selected two recently defined technologies, B-AMC (Broadband-VHF modified for L-band), and AMACS (VHF Digital Link Mode 4 combined with Enhanced TDMA) as well as Custom Satellite. For airport surface communications, the US and Europe agreed upon the IEEE 802.16e standard.

For oceanic and remote airspace, the US and Europe agreed upon Inmarsat SwiftBroadband and Custom Satellite technologies.

The FCS recognized the unique capabilities of satellite communications to provide coverage over large and/or remote geographic areas, but noted that the defined operational concept for 2020 is beyond the service horizon of current satellite systems. Next generation satellite systems may meet Phase 2 COCR requirements, particularly systems customized for aviation, including commercial solutions such as Iridium-NEXT and custom government/private solutions such as the European Space Agency initiative ATM SATCOM. The FCS recommendations for the satellite band are:

- *Continue monitoring the satellite system developments and assessment of specific technical solutions to be offered in the timeframe defined in the COCR as these next generation satellite systems become better defined;*
- *Update existing AMS(R)S SARPs performance requirements to meet future requirements; and*
- *In order to support the new AMS(R)S SARPs, consider the development of a globally applicable air interface standard for satellite communication systems supporting safety related communications.*

3. Iridium System Description

3.1 Basic Iridium Overview

The Iridium Communications System consists of three major components: the constellation of 66 satellites plus spares, the ground segment, and subscriber terminals called Iridium Subscriber Units (ISU) consisting of voice, data and paging equipment. The gateways perform call connection setup and administrative duties such as billing and resource management. The satellite constellation provides connectivity between users, from a user to the Iridium system gateway, and between gateways. The satellite constellation provides connectivity between ISUs and from an ISU to the Iridium gateway(s). Within the Iridium architecture, the satellites are cross-linked which allows ISU to ISU communication independent of gateway intervention once the call connection is established. The cross-linking allows a single gateway to handle all user functions regardless of user location. The gateways perform call connection setup, maintenance and tear-down and administrative duties.
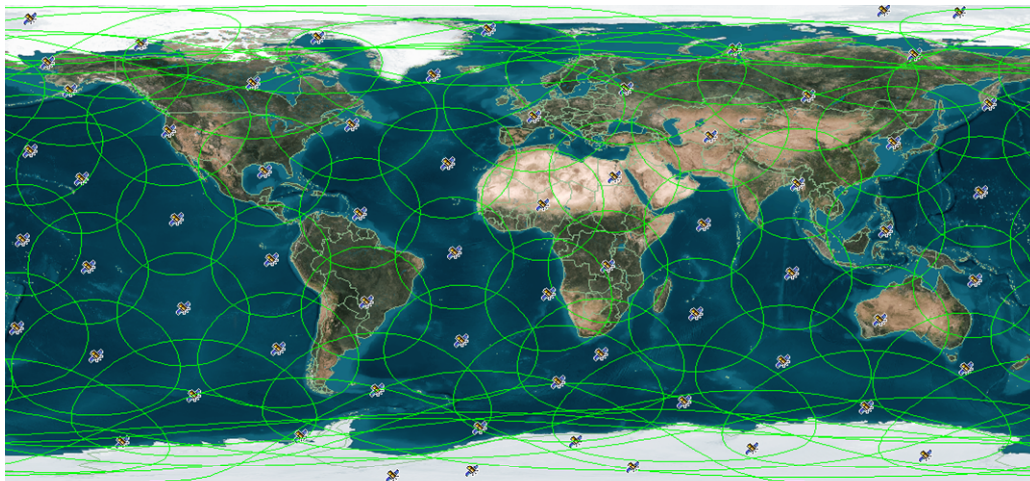
Figure 1: Iridium Satellite Coverage

3.1.1   Space Segment

The Iridium Communications System employs 66 low Earth orbit processing satellites that support user-to-user, user-to-gateway, and gateway-to-gateway communications. The 66 satellites are evenly distributed in six orbital planes with an 86.4° inclination, with one or more in-orbit spare for each orbital plane. Except for planes 1 and 6, the orbital planes are co-rotating and spaced 31.6° apart. The first and last orbital planes are spaced 22° apart and form a seam where the satellites are counter-rotating. The satellites orbit at 780 kilometers altitude with an orbital period of 100 minutes 28 seconds. The near polar orbits of the constellation provide global coverage from pole-to-pole as depicted in Figure 1.

The Iridium satellite itself is depicted in Figure 2. Each satellite supports three types of communication links – satellite-to-satellite, satellite-to-gateway, and satellite-to-subscriber. The satellites are interconnected via four Ka-band inter-satellite cross-links operating from 23.18 to 23.38 GHz at 12.5 Mbps half duplex. Each satellite communicates with the satellite immediately ahead and behind in its orbital plane (north/south) and to the nearest satellite in the two adjacent orbital planes (east/ west).

The satellite-to-gateway link is supported by four Ka-band feeder link antennas at a rate of 3.125 Mbps full duplex. The uplink frequency is from 29.1 to 29.3 GHz, and the downlink frequency is from 19.4 to 19.6 GHz. The feeder link antennas support calls originating or terminating at a gateway. Telemetry, tracking, and control facilities communicate with the satellite constellation through the Ka-band links.

The satellite-to-subscriber link uses three L-band antennas which project 48 spot beams, or cells, on the Earth, with each beam being approximately 600 km in diameter. Unlike terrestrial cellular where mobile users move through stationary cells, the Iridium cells move across the mobile user. The average satellite visibility time for a stationary Iridium user is about 10 minutes. The 66 satellite constellation has the potential to support 3,168 spot beams, however global coverage requires only 2,150 simultaneous beams. The L-band antenna uplinks and downlinks operate from 1616 to 1626.5 MHz. The satellite footprint, consisting of the 48 beams, is approximately 4700 km in diameter.

The on-board processing system of each satellite provides satellite control (telemetry, temperature and power control, and fault management) and supports communications routing of Iridium Transfer Mode (ITM) packets through the network. Each satellite routes ITM packets to its feeder link, cross-link, or subscriber link. The cross-linking capability is enabled through the dynamic on-board routing capability, allowing a signal to be dynamically routed between satellites until the appropriate user or gateway is within a satellite's footprint. This inter-satellite routing allows the system to rely solely on the mobile satellite system rather than regional infrastructures for long haul connectivity. It also allows signals to be cross-linked around a damaged satellite with minimal effect on caller connectivity. The Iridium satellites have a lifespan that fully supports service through 2014. In addition to the 66 operational satellites needed to provide real-time voice and data communications, Iridium maintains 9 on-orbit spare satellites, including 7 satellites that were launched in two separate launches in 2002.
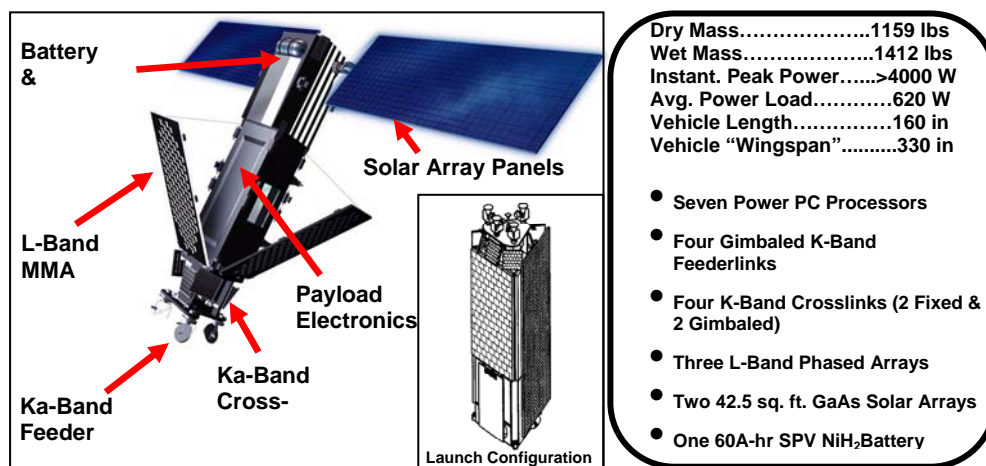
Figure 2: Iridium Satellite

3.1.2 Ground Segment

There is currently one commercial Iridium gateway in Tempe, Arizona, and a U.S. government owned and operated gateway in Hawaii. Each gateway generates and controls all user information pertaining to its registered users, such as user identity, geolocation and billing items. The gateway also provides connectivity from the Iridium Communications System to terrestrial based networks.

3.2 Iridium Aviation Subscribers

Overall Iridium currently serves over 270,000 subscribers, representing a 37% annual increase from the first quarter of 2007 to the first quarter of 2008. The subscriber base is 85% commercial and 15%

military/defense.   There are currently 17,000 aircraft with Iridium installations, a 51% increase from 2007 to 2008.   Iridium installed aircraft include general aviation, business aviation, air transport, specialized aviation, defense and government.   Applications include general voice and data communications, airline operational control communications, and air traffic services.

4. Standards Development for Iridium Aeronautical Safety Communications

The Iridium Communications System provides the space-borne sub-network for aviation datalink applications, connecting the aircraft avionics to a ground-based network.   Aeronautical communications service providers, such as ARINC and SITA, provide the connectivity to the ground-based users such as air traffic control authorities or airline flight operations, over terrestrial networks, as depicted in Figure 3.   The service providers generally provide connectivity through a number of different subnetworks, including VHF datalink, HF voice and datalink, and Inmarsat aeronautical services.   Digital communications for airline operational control (AOC) communications use ACARS (Aircraft Communications Addressing and Reporting System), a digital communications system operated over VHF channels.   In the mid 1990's the Future Air Navigation System (FANS) began operations in oceanic regions, enabling data messaging and position reporting over Inmarsat satellite links.   More recently, initial implementation of digital air traffic control messaging known as controller-pilot data link communications (CPDLC), transmitted over VHF Digital Link Mode 2 channels, has begun.   FANS and CPDLC perform similar functions using somewhat different formats.   For Iridium to play a role in ATS and AOC communications, it must provide similar services, and meet the same technical specifications.   Such specifications are embodied in aeronautical communications standards. Iridium has progressed through the standards process as described in the following subsections.
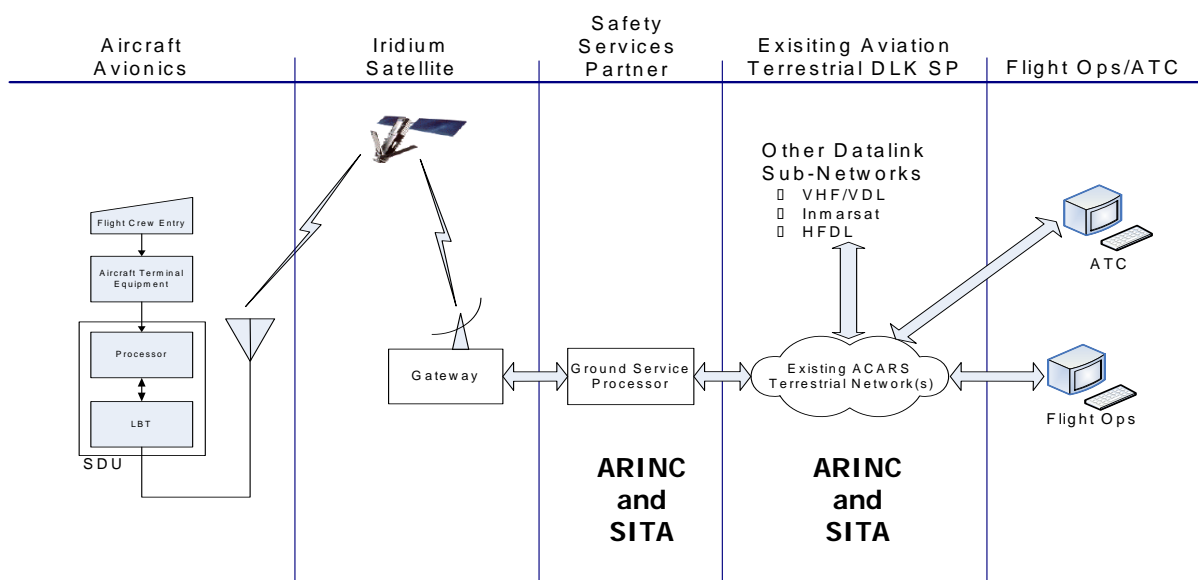

Figure 3 – Implementation of Aviation Datalink over Iridium

4.1 ICAO SARPs

ICAO develops technical standards as the basis for international interoperability of aviation systems, documented in Standards and Recommended Practices (SARPs).   Internationally approved, SARPs become part of the Annexes to the Convention on International Civil Aviation.

The Aeronautical Mobile Satellite (Route) Services, or AMS(R)S, SARPs apply to the use of satellite communications for aviation safety services.   As Inmarsat was previously the only satellite system capable of provided aeronautical safety services, these SARPs originally addressed Inmarsat-like performance.   Recently, to accommodate other satellite communications systems, the SARPs were revised to provide a more generic service requirements description, supported by a Technical Manual to verify the performance of individual systems in meeting SARPs requirements.   ICAO convened an Iridium Sub Working Group to develop the Iridium Technical Manual.   This Manual, and a supporting

Validation Report, provided the verification that the Iridium system meets the SARPs requirements, and also provides guidance on implementing an Iridium-based aeronautical safety communications capability. These documents were completed and approved by ICAO in November, 2007.

4.2 RTCA and AEEC standards

With standards for international interoperability established by ICAO, practical technical standards for implementation of systems become the domain of individual states who provide regulatory oversight for aircraft and air traffic management systems operating within their territories, and of industry groups charged with the actual manufacture and installation of systems.

The AEEC (formerly the Airline Electronic Engineering Committee) is an industry group that develops engineering standards and technical solutions for avionics, networks, and cabin systems. Iridium Satellite has been working with AEEC committees to develop a number of specifications in order to standardize the aircraft installation provisions (ARINC 761), support integration with other datalink systems (ARINC 618, 619, 620, 741 and 758), and document avionics data bus protocols (ARINC 429). The required changes to these documents have been incorporated and approved. The AEEC documents are "living documents", which are reviewed and changed on an as-needed-basis.

RTCA, Inc. (formerly Radio Technical Commission for Aeronautics) - develops consensus-based recommendations regarding communications, navigation, surveillance, and air traffic management system issues. RTCA functions as a Federal Advisory Committee. Its recommendations are used by the Federal Aviation Administration (FAA) as the basis for policy, program, and regulatory decisions and by the private sector as the basis for development, investment and other business decisions.

RTCA's Program Management Committee (PMC) convened a special committee (SC-215) to develop Iridium Satellite minimum operational standards for the avionics (DO-262) and for the Iridium Satellite network (DO-270), which would serve as a sub-network to the aviation terrestrial network, providing AMS(R)S safety service communications. DO-262 has been approved by the SC-215 committee and will be submitted to the PMC for final approval. DO-270 is expected to be completed by early 2009.

4.3 PARC CWG

Ultimately, the use of Iridium for air traffic control (ATC) communications will require regulatory approval, for example from the FAA in the US. The FAA authorizes working groups such as the FAA Performance Based Aviation Operational Rulemaking Committee (PARC) communications working group (CWG) to advance the evaluation and testing of systems seeking regulatory approval.

In late 2007, preliminary FANS 1/A over Iridium (FOI) tests assessed the feasibility of using Iridium as an ACARS sub-network to support FANS 1/A ATC data link applications, specifically CPDLC and automatic dependent surveillance-contract (ADS-C). After several successful live end-to-end FOI informal tests, participants to PARC CWG initiated the formal validation of Iridium as a viable sub-network supporting FANS 1/A data link applications [2].

The PARC CWG developed a project plan that defines the process that will be used to evaluate the Iridium sub-network with a goal of achieving approval as a viable sub-network for aeronautical safety services. The FOI operational evaluation is described in the next section. The results from this project will be used exclusively by the PARC-CWG to substantiate the recommendations to be submitted to the FAA on the enabling criteria needed to approve the use of Iridium for ATS data communications.

5. Operational Evaluation - FANS over Iridium

As described above, the PARC CWG is providing oversight to the FOI operational evaluation. The near term objective is to use Iridium as a viable sub-network for FANS 1/A applications supporting required communications performance (RCP) operations in different oceanic separation standards, for example, RCP-240 supporting reduced separation to 50 nmi longitudinal in required navigation performance 10 (RNP-10) airspace, and 30 nmi lateral / 30nmi longitudinal separation.

The mid term objective is to obtain operational approval of Iridium voice communications and data communications as a long range communication system equivalent to today's HF radios enabling

minimum equipment list relief to dispatch the aircraft with one HF radio inoperative. A longer term objective is to evaluate architectures that use dissimilar sub-networks, e.g., VHF, Iridium, Inmarsat, HFDL, to meet performance criteria required to support longer term oceanic/remote operations and regressed HF voice operations.

In addition to the PARC CWG and several FAA divisions, other participants in the FOI trials include Continental Airlines, Boeing, GE, Avionica, SITA, ARINC, UK NATS, NavCanada, Isavia, Airways Corporation New Zealand, JCAB, AirServices Australia, Cargolux, Quantas, and Iridium. The PARC CWG will coordinate activities with regional coordinating groups currently managing FANS services.

5.1 Project Description

Continental Micronesia Airlines (CMI) has configured nine Boeing 737-800 aircraft with an ARINC 741 compliant voice and data capable Iridium based SATCOM system. These aircraft will be equipped with a certified FANS 1/A package and Iridium SDUs. These aircraft, based in Guam and flying daily extended over-water operations outside of VHF coverage in airspace currently supporting FANS services will fly using FANS 1/A ATC data link services via CPDLC and ADS-C. Five aircraft will be configured to use the SITA network and other four will be configured to use the ARINC network.

A traditional phased testing plan with other sub-network media has been developed to qualify the Iridium sub-network. Both ARINC and SITA offer ACARS over Iridium (AOI) service, which is a prerequisite to offering FOI. Structured ground tests and monitored in-service tests will ensure the Iridium based sub-network performs as intended to support ATS. The three qualification phases are:

- ARINC Avionics Qualification Program (AQP) and/or SITA Validation Assessment and Qualification (VAQ)
- End-to-end ground tests prior to operational trial
- In-service operational trial

All of these have been completed for the avionics being used by CMI for the FOI in-service operational evaluation. A set of deliverables has been defined to provide a statistically sufficient data sample of CPDLC transactions (only those requiring W/U response) and ADS-C position reports.

The Iridium sub-network was bench tested and found acceptable to proceed with in-service operations. Coordination was also required with appropriate ATC ground systems to enable end-to-end operational evaluations. Boeing installed a representative Iridium based Satcom system into a 747 and 777 test bench at Boeing Field, Washington. This installation was able to connect to either SITA's or ARINC's live ACARS network. Boeing coordinated with various Pacific and Atlantic oceanic ATC facilities, including Oakland center (ZOA), to schedule formal live end-to-end evaluation tests.

The in-service trial will begin in the summer of 2008 lasting for approximately one year.

6. Iridium NEXT

6.1 Overview

The Iridium next-generation satellite constellation called NEXT is planned to seamlessly replace the current constellation to ensure mission continuity. It will maintain the attributes which make Iridium unique: global coverage, security, and availability, based on a LEO architecture. NEXT will have backward compatibility with applications and equipment used on the current Iridium System. NEXT will also provide new capabilities at higher data speed and bandwidth and offer flexibility in service delivery, enabling a new generation of services and user equipment. NEXT will have the potential for new applications beyond mobile communications, using open standard interfaces (e.g., IP based).

6.2 Enhanced Services

Current Iridium Communications System services will be maintained with backward compatibility with low data rate legacy voice and data services at 2.4 kbps. However, market demands require that NEXT offer a set of higher performance services to meet ever increasing customer needs. Satellite

systems take a significant period of time to design, develop and deploy and are expected to provide a useful mission life for 10-15 years. In addition, it is expected that significant investment will be made by terrestrial systems in technology and applications during the same period of time. Therefore, NEXT will be built on a flexible architecture to allow upgrading of the network to benefit from the technology investment of terrestrial systems and to meet the changing needs of our customers over time.

The Iridium Communications System customer base is widely diverse and geographically dispersed. The same satellite that may provide a substantial amount of short burst packet data service over North America may need to transition to a higher proportion of circuit switched, voice and broadband services over international waters. This capability is also essential to achieve maximum utilization of the NEXT network. The nature of the NEXT customer base will require the ability to dynamically assign power and bandwidth of system to meet the specific needs of mission critical applications over different parts of the globe. This is a fundamental principle of the NEXT system.

The anticipated services are legacy voice service with improved voice quality, and variety of L-band data services with rates ranging from 2.4 kbps to 1.5 Mbps, using bandwidth-on-demand. Data services offered range from Short Burst Data (SBD), broadband data (9.6 Kbps – 128 Kbps), high speed data (128 Kbps – 1.5 Mbps) and broadcast data service at rates up to 64 Kbps. Fixed and transportable Ka band services in data rates up to 10 Mbps will be offered. Also planned are private network gateways and virtual private gateways. Aeronautical services are planned for altitudes up to 30 Km above mean sea level, and at speeds up to 2800 Km/hr.

6.3 Application to Future Aeronautical Communications

The planned service offerings of Iridium NEXT have been defined in the previous subsection. The detailed design of Iridium NEXT has not yet commenced, so detailed technical specifications related to aeronautical safety communications are not yet available. From the satellite communications analyses performed for the FCS, two key issues affected the ability of satellite systems to meet future COCR Phase 2 requirements: system availability and communications capacity. Both of these issues, as well as other technical performance specifications, will need to be analyzed when sufficient design details are available. However, the significant increase in data rates and overall communications capacity planned for Iridium NEXT are promising in terms of meeting COCR requirements. System availability, which is impacted by system failure rates and recovery times, is adequate in the current Iridium system only for oceanic/remote/polar operations. It is unknown at this time whether Iridium NEXT will be able to meet COCR availability requirements in other operating regions.

7. Summary

Satellite communications will play a larger role in the future air transportation system. Next-generation satellite systems will be assessed for their ability to meet future requirements, such as those identified in the FCS COCR. To date, only Inmarsat has provided aeronautical safety communications by satellite. However, the current Iridium satellite system now has compatible avionics installed in over 17,000 aircraft and is providing a number of voice and data services. Progress has been made in the process of standardizing Iridium service for providing safety critical communications, including AOC and ATC. International standardization has been completed, while at the national and industry level the standards process may be completed by early 2009. Operational evaluations will demonstrate Iridium performance for FANS services in oceanic areas, which would likely be the first operational Iridium safety services. With this foundation, the development of Iridium NEXT provides the potential for expanded aeronautical safety communications services in the future, enabling a valuable new data communications subnetwork to support next generation air transportation around the world.

8. References

[1] Phillips, B., Pouzet, J., Budinger, J., and Fistas, N. "Future Communication Study - Action Plan 17 Final Conclusions and Recommendations Report", ICAO ACP WGT-1 Working Paper 6.

[2] FANS 1/A over Iridium (FOI) Project Plan, FAA Performance Based Aviation Operational Rulemaking Committee Communications Working Group, 18 May 2008.